

## 5. Solvent and Other Product Use

Greenhouse gas emissions are produced as a by-product of various solvent and other product uses. In the United States, emissions from nitrous oxide (N<sub>2</sub>O) product usage, the only source of greenhouse gas emissions from this sector, accounted for less than 0.1 percent of total U.S. anthropogenic greenhouse gas emissions on a carbon equivalent basis in 2004 (see Table 5-1). Indirect greenhouse gas emissions also result from solvent and other product use, and are presented in Table 5-2 in teragrams of CO<sub>2</sub> equivalent (Tg CO<sub>2</sub> Eq.) and gigagrams (Gg).

### 5.1. Nitrous Oxide Product Usage (IPCC Source Category 3D)

N<sub>2</sub>O is a clear, colorless, oxidizing liquefied gas, with a slightly sweet odor. N<sub>2</sub>O is produced by thermally decomposing ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>), a chemical commonly used in fertilizers and explosives. The decomposition creates steam (H<sub>2</sub>O) and N<sub>2</sub>O through a low-pressure, low-temperature (500°F) reaction. Once the steam is removed through condensation, the remaining N<sub>2</sub>O is purified, compressed, dried, and liquefied for storage and distribution. Two companies operate a total of five N<sub>2</sub>O production facilities in the United States (CGA 2002).

N<sub>2</sub>O is primarily used in carrier gases with oxygen to administer more potent inhalation anesthetics for general anesthesia and as an anesthetic in various dental and veterinary applications. As such, it is used to treat short-term pain, for sedation in minor elective surgeries, and as an induction anesthetic. The second main use of N<sub>2</sub>O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. Small quantities of N<sub>2</sub>O also are used in the following applications:

**Table 5-1: N<sub>2</sub>O Emissions from Solvent and Other Product Use (Tg CO<sub>2</sub> Eq. and Gg)**

Gas/Source	1990	1998	1999	2000	2001	2002	2003	2004
N <sub>2</sub> O Product Usage								
Tg CO <sub>2</sub> Eq.	4.3	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Gg	14	15	15	15	15	15	15	15

**Table 5-2: Indirect Greenhouse Gas Emissions from Solvent and Other Product Use (Gg)**

Gas/Source	1990	1998	1999	2000	2001	2002	2003	2004
NMVOCs	5,217	4,671	4,569	4,384	4,547	4,256	4,262	4,267
CO	4	1	46	46	45	46	46	46
NO <sub>x</sub>	1	3	3	3	3	6	6	6

**Table 5-3: N<sub>2</sub>O Emissions from N<sub>2</sub>O Product Usage (Tg CO<sub>2</sub> Eq. and Gg)**

Year	Tg CO <sub>2</sub> Eq.	Gg
1990	4.3	14
1998	4.8	15
1999	4.8	15
2000	4.8	15
2001	4.8	15
2002	4.8	15
2003	4.8	15
2004	4.8	15

- Oxidizing agent and etchant used in semiconductor manufacturing;
- Oxidizing agent used, with acetylene, in atomic absorption spectrometry;
- Production of sodium azide, which is used to inflate airbags;
- Fuel oxidant in auto racing; and
- Oxidizing agent in blowtorches used by jewelers and others (Heydorn 1997).

Production of N<sub>2</sub>O in 2004 was approximately 17 Gg. N<sub>2</sub>O emissions were 4.8 Tg CO<sub>2</sub> Eq. (15 Gg) in 2004 (see Table 5-3). Production of N<sub>2</sub>O stabilized during the 1990s because medical markets had found other substitutes for anesthetics, and more medical procedures were being performed on an outpatient basis using local anesthetics that do not require N<sub>2</sub>O. The use of N<sub>2</sub>O as a propellant for whipped cream has also stabilized due to the increased popularity of cream products packaged in reusable plastic tubs (Heydorn 1997).

## Methodology

Emissions from N<sub>2</sub>O product usage were calculated by first multiplying the total amount of N<sub>2</sub>O produced in the United States by the share of the total quantity of N<sub>2</sub>O that is used by each sector. This value was then multiplied by the associated emissions rate for each sector. After the emissions were calculated for each sector, they were added together to obtain a total estimate of N<sub>2</sub>O product usage emissions. Emissions were determined using the following equation:

$$\begin{aligned} \text{N}_2\text{O Product Usage Emissions} = & \sum_i [\text{Total U.S. Production of N}_2\text{O}] \times \\ & [\text{Share of Total Quantity of N}_2\text{O Usage by Sector } i] \times \\ & [\text{Emissions Rate for Sector } i], \end{aligned}$$

where,

$i$  = sector.

The share of total quantity of N<sub>2</sub>O usage by subcategory represents the share of national N<sub>2</sub>O produced that is used by the specific subcategory (i.e., anesthesia, food processing, etc.). In 2004, the medical/dental industry used an estimated 86 percent of total N<sub>2</sub>O produced, followed by food processing propellants at 6.5 percent. All other categories combined used the remainder of the N<sub>2</sub>O produced. This subcategory breakdown has changed only slightly over the past decade. For instance, the small share of N<sub>2</sub>O usage in the production of sodium azide has declined significantly during the decade of the 1990s. Due to the lack of information on the specific time period of the phase-out in this market subcategory, most of the N<sub>2</sub>O usage for sodium azide production is assumed to have ceased after 1996, with the majority of its small share of the market assigned to the larger medical/dental consumption subcategory. The N<sub>2</sub>O was allocated across these subcategories, a usage emissions rate was then applied for each sector to estimate the amount of N<sub>2</sub>O emitted.

Only the medical/dental and food propellant subcategories were estimated to release emissions into the atmosphere, and therefore these subcategories were the only usage subcategories with emission rates. For the medical/dental subcategory, due to the poor solubility of N<sub>2</sub>O in blood and other tissues, approximately 97.5 percent of the N<sub>2</sub>O is not metabolized during anesthesia and quickly leaves the body in exhaled breath. Therefore, an emission factor of 97.5 percent was used for this subcategory (Tupman 2002). For N<sub>2</sub>O used as a propellant in pressurized and aerosol food products, none of the N<sub>2</sub>O is reacted during the process and all of the N<sub>2</sub>O is emitted to the atmosphere, resulting in an emissions factor of 100 percent for this subcategory (Heydorn 1997). For the remaining subcategories, all of the N<sub>2</sub>O is consumed/reacted during the process, and therefore the emissions rate was considered to be zero percent (Tupman 2002).

The 1990 through 1992 and 1996 N<sub>2</sub>O production data were obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997). These data were provided as a range. For example, in 1996, Heydorn (1997) estimates N<sub>2</sub>O production to range between 13.6 and 18.1 thousand metric tons. Tupman (2003) provided a narrower range for 1996 that falls within the production bounds described by Heydorn (1997). These data are considered more industry specific and current. The midpoint of the narrower production range (15.9 to 18.1 thousand metric tons) was used to estimate N<sub>2</sub>O emissions for years 1993 through 2002 (Tupman 2003). Production data for 2004 was assumed to equal 2002 data. N<sub>2</sub>O production data for 1990 through 2004 are presented in Table 5-4.

The 1996 share of the total quantity of N<sub>2</sub>O used by each subcategory was obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997). The 1990 through 1995 share of total quantity of N<sub>2</sub>O used by each subcategory was kept the same as the 1996 number provided by SRI Consulting. The 1997 through 2002 share of total quantity of N<sub>2</sub>O usage by sector was obtained from communication with a N<sub>2</sub>O industry expert (Tupman 2002). Due to unavailable data, the share of total quantity of N<sub>2</sub>O usage data for 2004 was assumed to equal that of 2002. The emissions rate for the food processing propellant industry was obtained from SRI Consulting's *Nitrous Oxide, North America* report (Heydorn 1997), and confirmed by a N<sub>2</sub>O industry expert (Tupman 2002). The emissions rate for all other subcategories was obtained from communication with a N<sub>2</sub>O industry expert (Tupman 2002). The emissions rate

**Table 5-4: N<sub>2</sub>O Production (Gg)**

Year	Gg
1990	16
1991	15
1992	15
1993	17
1994	17
1995	17
1996	17
1997	17
1998	17
1999	17
2000	17
2001	17
2002	17
2003	17
2004	17

for the medical/dental subcategory was substantiated by the *Encyclopedia of Chemical Technology* (Othmer 1990).

## Uncertainty

The overall uncertainty associated with the 2004 N<sub>2</sub>O emissions estimate from N<sub>2</sub>O product usage was calculated using the Intergovernmental Panel on Climate Change (IPCC) *Good Practice Guidance* Tier 2 methodology. Uncertainty associated with the parameters used to estimate N<sub>2</sub>O emissions included that of production data, total market share of each end use, and the emission factors applied to each end use, respectively. The activity data inputs and their associated uncertainties and distributions are summarized in Table 5-5.

**Table 5-5: Sources of Uncertainty in N<sub>2</sub>O Emissions from N<sub>2</sub>O Product Usage**

Variable	Value	Distribution Type	Uncertainty Range <sup>a</sup>		Reference
			Lower Bound	Upper Bound	
Production (Gg)	17	Uniform	-7%	+7%	Expert Judgment
Market Share Medicine/Dentistry Anesthesia (analgesic property) (%)	0.86	Uniform	-2%	+2%	Expert Judgment
Market Share Food Processing Propellant (%)	0.06	Uniform	-23%	+23%	Expert Judgment
Emission Rate Medicine/Dentistry Anesthesia (analgesic property) (%)	0.98	Uniform	-3%	+3%	Expert Judgment

<sup>a</sup> Parameters presented represent upper and lower bounds as a percentage of the mean, based on a 95 percent confidence interval.

**Table 5-6: Tier 2 Quantitative Uncertainty Estimates for N<sub>2</sub>O Emissions From N<sub>2</sub>O Product Usage (Tg CO<sub>2</sub> Eq. and Percent)**

Source	Gas	2004 Emission Estimate (Tg CO <sub>2</sub> Eq.)	Uncertainty Range Relative to Emission Estimate <sup>a</sup>			
			(Tg CO <sub>2</sub> Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
N <sub>2</sub> O Product Usage	N <sub>2</sub> O	4.8	4.4	5.1	-7%	+7%

<sup>a</sup> Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

The results of this Tier 2 quantitative uncertainty analysis are summarized in Table 5-6. N<sub>2</sub>O emissions from N<sub>2</sub>O product usage were estimated to be between 4.4 and 5.1 Tg CO<sub>2</sub> Eq. at the 95 percent confidence level (or in 19 out of 20 Monte Carlo Stochastic Simulations). This indicates a range of approximately 7 percent below to 7 percent above the 2004 emissions estimate of 4.8 Tg CO<sub>2</sub> Eq.

## Planned Improvements

Planned improvements include a continued evaluation of alternative production statistics for cross verification and a reassessment of subcategory usage to accurately represent the latest trends in the product usage.

## 5.2. Indirect Greenhouse Gas Emissions from Solvent Use

The use of solvents and other chemical products can result in emissions of various ozone precursors (i.e., indirect greenhouse gases).<sup>1</sup> Non-methane volatile organic compounds (NMVOCs), commonly referred to as “hydrocarbons,” are the primary gases emitted from most processes employing organic or petroleum based solvents. As some of industrial applications also employ thermal incineration as a control technology, combustion by-products, such as carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>), are also reported with this source category. Surface coatings accounted for approximately 41 percent of NMVOC emissions from solvent use in 2004, while “non-industrial”<sup>2</sup> uses accounted

for about 38 percent and degreasing applications for 7 percent. Overall, solvent use accounted for approximately 25 percent of total U.S. emissions of NMVOCs in 2004; NMVOC emissions from solvent use have decreased 18 percent since 1990.

Although NMVOCs are not considered direct greenhouse gases, their role as precursors to the formation of ozone—which is a greenhouse gas—results in their inclusion in a greenhouse gas inventory. Emissions from solvent use have been reported separately by the United States to be consistent with the inventory reporting guidelines recommended by the IPCC. These guidelines identify solvent use as one of the major source categories for which countries should report emissions. In the United States, emissions from solvents are primarily the result of solvent evaporation, whereby the lighter hydrocarbon molecules in the solvents escape into the atmosphere. The evaporation process varies depending on different solvent uses and solvent types. The major categories of solvent uses include degreasing, graphic arts, surface coating, other industrial uses of solvents (i.e., electronics, etc.), dry cleaning, and non-industrial uses (i.e., uses of paint thinner, etc.).

Total emissions of NO<sub>x</sub>, NMVOCs, and CO from 1990 to 2004 are reported in Table 5-7.

## Methodology

Emissions were calculated by aggregating solvent use data based on information relating to solvent uses from different applications such as degreasing, graphic arts, etc.

<sup>1</sup> Solvent usage in the United States also results in the emission of small amounts of hydrofluorocarbons (HFCs) and hydrofluoroethers (HFEs), which are included under Substitution of Ozone Depleting Substances in the Industrial Processes chapter.

<sup>2</sup> “Non-industrial” uses include cutback asphalt, pesticide application, adhesives, consumer solvents, and other miscellaneous applications.

**Table 5-7: Emissions of NO<sub>x</sub>, CO, and NMVOC from Solvent Use (Gg)**

Activity	1990	1998	1999	2000	2001	2002	2003	2004
<b>NO<sub>x</sub></b>	<b>1</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>3</b>	<b>6</b>	<b>6</b>	<b>6</b>
Degreasing	+	+	+	+	+	+	+	+
Graphic Arts	+	1	+	+	+	+	+	+
Dry Cleaning	+	+	+	+	+	+	+	+
Surface Coating	1	2	3	3	3	6	6	6
Other Industrial Processes <sup>a</sup>	+	+	+	+	+	+	+	+
Non-Industrial Processes <sup>b</sup>	+	+	+	+	+	+	+	+
Other	NA	+	+	+	+	+	+	+
<b>CO</b>	<b>4</b>	<b>1</b>	<b>46</b>	<b>46</b>	<b>45</b>	<b>46</b>	<b>46</b>	<b>46</b>
Degreasing	+	+	+	+	+	+	+	+
Graphic Arts	+	+	+	+	+	+	+	+
Dry Cleaning	+	+	+	+	+	+	+	+
Surface Coating	+	1	46	46	45	46	46	46
Other Industrial Processes <sup>a</sup>	4	+	+	+	+	+	+	+
Non-Industrial Processes <sup>b</sup>	+	+	+	+	+	+	+	+
Other	NA	+	+	+	+	+	+	+
<b>NMVOCs</b>	<b>5,217</b>	<b>4,671</b>	<b>4,569</b>	<b>4,384</b>	<b>4,547</b>	<b>4,256</b>	<b>4,262</b>	<b>4,267</b>
Degreasing	675	337	363	316	331	310	310	311
Graphic Arts	249	272	224	222	229	214	214	214
Dry Cleaning	195	151	267	265	272	254	255	255
Surface Coating	2,289	1,989	1,865	1,767	1,863	1,744	1,746	1,748
Other Industrial Processes <sup>a</sup>	85	101	95	98	103	97	97	97
Non-Industrial Processes <sup>b</sup>	1,724	1,818	1,714	1,676	1,707	1,598	1,600	1,602
Other	+	3	40	40	42	40	40	40

<sup>a</sup> Includes rubber and plastics manufacturing, and other miscellaneous applications.

<sup>b</sup> Includes cutback asphalt, pesticide application, adhesives, consumer solvents, and other miscellaneous applications.

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.5 Gg.

Emission factors for each consumption category were then applied to the data to estimate emissions. For example, emissions from surface coatings were mostly due to solvent evaporation as the coatings solidify. By applying the appropriate solvent-specific emission factors to the amount of solvents used for surface coatings, an estimate of emissions was obtained. Emissions of CO and NO<sub>x</sub> result primarily from thermal and catalytic incineration of solvent-laden gas streams from painting booths, printing operations, and oven exhaust.

These emission estimates were obtained from preliminary data (EPA 2005), and disaggregated based on EPA (2003), which, in its final iteration, will be published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site. Emissions were calculated either for individual categories or for many categories combined, using basic activity data (e.g., the amount of solvent purchased) as an

indicator of emissions. National activity data were collected for individual applications from various agencies.

Activity data were used in conjunction with emission factors, which together relate the quantity of emissions to the activity. Emission factors are generally available from the EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA 1997). The EPA currently derives the overall emission control efficiency of a source category from a variety of information sources, including published reports, the 1985 National Acid Precipitation and Assessment Program emissions inventory, and other EPA databases.

## Uncertainty

Uncertainties in these estimates are partly due to the accuracy of the emission factors used and the reliability of correlations between activity data and actual emissions.

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